

TITLE OF THE INVENTION

METHOD OF GENERATING PARITY DATA BASED ON LOW-DENSITY PARITY CHECK MATRIX AND APPARATUS THEREFOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of Korean Patent Application No. 2003-5927, filed on January 29, 2003, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates to a method of error correction and signal detection, and more particularly to, a method of generating parity data based on low-density parity check matrices and an apparatus therefor.

2. Description of the Related Art

[0003] A conventional coding method based on Low Density Parity Check (LDPC) codes for error correction generates parity check codes that have a predetermined number of elements having a value of one in rows and columns of the parity check codes, and then generates parity data based on the parity check codes.

[0004] That is, in the coding method based on the LDPC codes, a parity check matrix H having a predetermined number of elements having a value of one in its rows and columns is formed, and a codeword x satisfying the equation $Hx=0$ is obtained.

[0005] The codeword x includes original data and parity data.

[0006] In order to obtain the parity data, the parity check matrix H is converted into a generator matrix G by Gaussian elimination, or into a lower triangular form. Since the generator matrix G is no longer a sparse matrix, increased computational time is required for calculating the codeword x .

[0007] A conventional parity check code matrix H of the form $\begin{bmatrix} A & B & T \\ C & D & E \end{bmatrix}$ is shown in FIG. 1.

[0008] To obtain the codeword x satisfying the equation $Hx=0$, triangulation of the parity check code matrix H is performed, and then pre-multiplication using Gaussian elimination is carried out, as shown in the following equation (1).

$$\begin{bmatrix} I & 0 \\ -ET^{-1} & I \end{bmatrix} \begin{bmatrix} A & B & T \\ C & D & E \end{bmatrix} = \begin{bmatrix} A & B & T \\ -ET^{-1}A + C & -ET^{-1}B + D & 0 \end{bmatrix} \quad (1)$$

[0009] However, the above calculation process is highly complex and time consuming.

[0010] The basic concept of the LDPC is described by D. J. Mackay, in "Good Error-Correction Codes Based on Very Sparse Matrices", IEEE Trans. on Information Theory, vol. 45, No. 2, pp.399-431, 1999, and a conventional implementation of the H matrix is presented by T. Richardson and R. Urbanke in "Efficient Encoding of Low-Density Parity-Check Codes", IEEE Trans. on Information Theory, vol. 47, No. 2, pp. 638-656, 2001.

SUMMARY OF THE INVENTION

[0011] The present invention provides a method of efficiently generating parity data based on low-density parity check matrices and an apparatus therefor.

[0012] In accordance with an aspect of the present invention, a method of generating parity data is provided based on a parity check matrix H having p codewords of length c, each codeword being divided in a message word of length m and parity data of length p. The method includes reordering columns of the parity check matrix H based on elements in each column having values of one to generate a reordered parity check matrix H', determining a cross-point I between a diagonal line L2 of a parity matrix part Mp in the parity check matrix H' and a reordered diagonal line L1 defined by a first entry of an element having a value of one in each column of the reordered parity check matrix H' in rows above a horizontal line L3 that passes through the cross-point I to perform column permutations on the reordered parity check matrix H' to generate a triangular matrix T. The method further includes using the triangular matrix T and the message words to obtain the parity data and satisfying the equation $Hx=0$, where x is a codeword matrix, to obtain the remaining parity data.

[0013] According to an aspect of the invention, the reordering columns of the parity check matrix H based on elements in each column includes finding a first entry of an element having a value of one in each column in the parity check matrix H , and reordering the columns from left to right in the order of the highest entry of an element having a value of one in each column.

[0014] According to an aspect of the invention, the determining a cross-point I includes, with regard to elements above the horizontal line $L3$, sequentially exchanging from left to right columns of a message matrix part M_m with columns of the parity matrix part M_p in the reordered parity check matrix H' .

[0015] According to an aspect of the invention, the using the triangular matrix T and the message words to obtain the parity data is performed by a backward-substitution method.

[0016] According to an aspect of the invention, the satisfying the equation $Hx=0$ to obtain the remaining parity data is performed by a Gaussian elimination method.

[0017] In accordance with another aspect of the present invention, a method of generating parity information is provided based on a parity check matrix H having p codewords of length c , each codeword being divided in a message word of length m and parity data of length p . The method comprises reordering columns in the parity check matrix H based on elements in each column having values of one to obtain a reordered parity check matrix H' , determining a cross-point I between a diagonal line $L2$ of a parity matrix part M_p that corresponds to a parity information part in the parity check matrix H' and a reordered diagonal line $L1$ defined by a first entry of an element having a value of one in each column of the reordered parity check matrix H' , and, on the basis of positions of elements having a value of one in rows above a horizontal line $L3$ that pass through the cross-point I to perform column permutations on the reordered parity check matrix H' , forming a triangular matrix T . The method further includes, for rows under the horizontal line $L3$, performing row and column permutation based on the positions of the elements having a value of one in the rows to form an extended triangular matrix T , and using the extended triangular matrix T and the message words to obtain the parity data.

[0018] According to an aspect of the present invention, the using the triangular matrix T and the message words to obtain the parity data includes checking whether there is a row under the horizontal line $L3$, in which a second element from right to left having a value of one is on the left of the diagonal line $L2$ of the parity matrix part M_p in the reordered parity check matrix H' ,

and if such a row exists, exchanging the row with a top-most row under the horizontal line L3 and exchanging a first column having an element having a value of one in the new exchanged top-most row to the right of the diagonal line L2 with a second column having an element having a value of one in the newly exchanged top-most row to the nearest left of the diagonal line L2. According to an aspect of the present invention, these operations are repeatedly performed until a row no longer exists, in which a second element from right to left having a value of one is to the left of the diagonal line L2.

[0019] According to an aspect of the present invention, the using the extended triangular matrix T and the message words to obtain the parity data includes generating a part of the parity data using the extended triangular matrix and the message words. According to an aspect of the present invention, the generating is performed by backward-substitution calculation.

[0020] According to an aspect of the present invention, the using the extended triangular matrix T and the message words to obtain the parity data includes generating remaining parts of parity data by Gaussian elimination.

[0021] In accordance with yet another aspect of the present invention, an apparatus is provided for generating parity information based on a parity check matrix H having p codewords of length c, each codeword being divided into a message word of length m and parity data of length p. The apparatus includes a parity check matrix generator for reordering columns in the parity check matrix H, based on elements in each column having a value of one to generate a reordered parity check matrix H', a triangular matrix generator for determining a cross-point I between a diagonal line L2 of a parity matrix part Mp in the parity check matrix H' and a reordered diagonal line L1 defined by a first entry of an element having a value of one in each column of the reordered parity check matrix H', and, on the basis of positions of elements having a value of one in rows above a horizontal line L3 that passes through the cross-point I to perform column permutations on the reordered parity check matrix H', for generating a triangular matrix T. The apparatus also includes a calculator for using the triangular matrix T and the message words to obtain the parity data and a calculator to find values for satisfying the equation $Hx=0$, where x is a codeword matrix, to obtain the remaining parity data.

[0022] According to an aspect of the present invention, the parity check matrix generator for reordering columns finds a top position of an element having a value of one in each column in

the parity check matrix H , and reorders columns from left to right in the order of highest entry of the element having a value of one in each column.

[0023] According to an aspect of the present invention, the triangular matrix generator for determining a cross-point I and using positions of elements having a value of one sequentially exchanges from left to right columns of a message matrix part M_m with columns of the parity matrix part M_p in the reordered parity check matrix H' , with regard to positions of an element with respect to the horizontal line L_3 .

[0024] According to an aspect of the present invention, the calculator for using the triangular matrix T and the message words generates parity data by backward-substitution calculation using the triangular matrix T .

[0025] According to an aspect of the present invention, the triangular matrix generator for determining a cross-point I and for using positions of elements having a value of one generates the parity data by Gaussian elimination.

[0026] According to still another aspect of the present invention, an apparatus is provided for generating parity information based on a parity check matrix H having p codewords of length c , each codeword being divided into a message word of length m and parity data of length p . The apparatus includes a parity check matrix generator for reordering columns in the parity check matrix H , based on elements in each column having values of one to generate a reordered parity check matrix H' , a triangular matrix generator for determining a cross-point I between a diagonal line L_2 of a parity matrix part M_p in the parity check matrix H and a reordered diagonal line L_1 defined by first entry of an element having a value of one in each column of the reordered parity check matrix H' , and, on the basis of positions of elements having a value of one in rows above a horizontal line L_3 that passes through the cross-point I to perform column permutations on the reordered parity check matrix H' to generate a triangular matrix T . The apparatus also includes a column permutator for performing row and column permutation based on the positions of elements having a value of one in the rows to form an extended triangular matrix T , for rows under the horizontal line L_3 , and a calculator calculating values using the extended triangular matrix T and the message words to generate the parity data.

[0027] According to an aspect of the present invention, the column permutator for performing row and column permutation includes a checker for checking whether there is a row

under the horizontal line L3, in which a second element from right to left having a value of one in the row is on the left of the diagonal line L2 of the parity matrix part M_p in the reordered parity check matrix H' , a first exchanger for exchanging the row with a top-most row under the horizontal line L3, and a second exchanger for exchanging a first column having an element having a value of one in the newly exchanged top-most row on the right of the diagonal line L2 with a second column having an element having a value of one in the same top-most row on the nearest left of the diagonal line L2.

[0028] According to an aspect of the present invention, the calculator calculating values using the extended triangular matrix T includes a calculator to generate part of parity data by a backward substitution calculation using the extended triangular matrix and the message words.

[0029] According to an aspect of the present invention, the calculator calculates values using the extended triangular matrix T to generate remaining parity data by Gaussian elimination.

[0030] Additional aspects and/or advantages of the invention will be set forth in part in the description which follows and, in part, will be obvious from the description, or may be learned by practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] These and/or other aspects and advantages of the invention will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings in which:

FIG. 1 shows a conventional structure of an H matrix used to obtain parity for error correction;

FIG. 2 is a block diagram of an aspect of an apparatus for generating parity data based on low-density parity check matrices, according to an aspect of the present invention;

FIGS. 3A through 3C illustrate how the parity check matrix is re-structured by a column permutation unit of FIG. 2;

FIGS. 4A through 4D show parity check matrices H for generating parity data, according to an aspect of the present invention; and

FIG. 5 is a flowchart of a method of generating parity data based on low-density parity check matrices, according to an aspect of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0032] Reference will now be made in detail to the embodiments of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to the like elements throughout. The embodiments are described below to explain the present invention by referring to the figures.

[0033] Aspects of the present invention are embodied in many different forms and should not be construed as being limited to the embodiments set forth herein; rather these embodiments are provided so that this disclosure conveys a description of some aspects of the invention to those skilled in the art.

[0034] According to an aspect of the present invention, the modification to a parity check matrix is restricted to column or row permutation.

[0035] Even if all columns or rows are exchanged, separate equations are formed using the parity check matrix, so that the column or row permutation does not affect generation of parity data.

[0036] FIG. 2 is a block diagram of an aspect of the present invention of an apparatus for generating parity data based on low-density parity check matrices.

[0037] The apparatus includes a parity check matrix generator 210, a column permutator 220, a triangular matrix generator 230, a triangular matrix extender 240, a backward substitution calculator 250, and a lower part parity calculator 260.

[0038] Operations of the apparatus of FIG. 2 will now be described with reference to FIGS. 3A through 3C in conjunction with FIGS. 4A through 4D.

[0039] Referring to FIG. 2, the parity check matrix generator 210 generates a parity check matrix H with p rows, corresponding to a length of parity data, and c columns, corresponding to a length of a codeword.

[0040] Elements of the parity check matrix H have values of zero or one, and the number of elements having a value of one is less than that of the number of elements having a value of zero

[0041] The column permutator 220 reconstructs the parity check matrix H generated by the parity check matrix generator 210 by reordering the columns from left to right such that the upper most elements having values of one in each column are arranged, for example, along a diagonal line $L1$.

[0042] In other words, in FIG. 3A, column permutation is performed such that columns having a higher first entry of an element having a value of one are arranged from left to right.

[0043] For example, a dotted line $L1$ in FIG. 3A represents a reordered diagonal line that connects the upper-most positions of elements having a value of one in the reordered columns.

[0044] FIG. 3B shows the reordered parity check matrix H' . The reordered parity check matrix H' is divided into a message matrix part M_m having p message words, the length of each message word being m in a horizontal direction, and a parity matrix part M_p having p parities, the length of each parity being p in a horizontal direction.

[0045] A diagonal line $L2$ in the parity matrix part M_p represents a line that connects diagonal elements in the parity matrix part M_p . FIG. 3C shows the column permutation process by the triangular matrix generator 230.

[0046] The triangular matrix generator 230 forms a triangular matrix T as shown in FIG. 4A, by performing column permutation on the reordered parity check matrix H' .

[0047] In FIG. 3C, a solid line $L1$ represents the same reordered diagonal line $L1$ shown in FIG. 3A, another solid line $L2$ represents the same diagonal line $L2$ of the parity matrix part shown in FIG 3B, and an index I represents a cross-point of $L1$ and $L2$.

[0048] A dotted line $L3$ is a horizontal line that passes through the cross-point I .

[0049] In column permutation, the first column exchange is performed between the leftmost columns of the message matrix part M_m and the parity matrix part M_p .

[0050] That is, first columns C1 and Cx are exchanged first, then columns C2 and Cx-1 are exchanged, and so on. The resulting triangular matrix T is shown in FIG. 4A.

[0051] FIG. 4A shows the parity check matrix that includes the triangular matrix T. An upper-right part of the triangular matrix T contains elements having only a value of zero, an upper part of remaining columns resulted from excluding the permuted k columns from p columns in the parity matrix part Mp with respect to the horizontal line L3 containing elements having a value of zero, and a lower part of the remaining columns with respect to the horizontal line L3 defines a matrix C of the parity check matrix and includes elements having a value of zero and one.

[0052] The triangular matrix extension unit 240 sequentially performs a plurality of row permutations and column permutations as shown in FIG 4B and 4C to diagonalize the undiagonalized matrix C to the maximum possible extent.

[0053] FIG. 4B and 4C show the row and column permutation processes performed by the triangular matrix extension unit 240.

[0054] Referring to FIG. 4B, comparing all the rows under the horizontal line L3, a row in which a second element from right to left of all elements having a value of one to the left of the diagonal line L2 is extracted, e.g., row R3 in FIG. 4B, and exchanged with a row R1, i.e., the upper-most row under the horizontal line L3. If there is no row meeting the condition that the second element having a value of one from the right end of the matrix is to the left of the diagonal line L2, the triangular matrix extension process performed by the triangular matrix extender 240 is finished.

[0055] Thereafter, as shown, for example, in FIG. 4C, a column Cq having an element with a value of one in the row R3 to the right of the diagonal line L2, is exchanged with a column Cp having an element with a value of one in the row R3 to the left of the diagonal line L2.

[0056] If there is no column having an element with a value of one in the row in an extracted row to the right of the diagonal line L2 column permutation is no longer performed, and the triangular extension process is stopped.

[0057] The row and column permutations are repeatedly performed until a row no longer exists in which a second element from right to left having a value of one is on the left of the

diagonal line L2, and thereby the lower part of the triangular matrix T is extended as much as possible so as to make the matrix C of the parity check matrix as small as possible.

[0058] FIG. 4D shows a part of the triangular matrix extended by the triangular matrix extension unit 240.

[0059] Since a single column has been exchanged according to the aspect of the present invention shown in FIG. 4B and 4C, the triangular matrix T is extended by 1x1 bits in horizontal and vertical directions.

[0060] The backward-substitution calculator 250 performs a backward substitution calculation using message bits and the area of the triangular matrix extended by the triangular matrix extension unit 240, thereby obtaining values of parity bits (or parity data). This calculation is represented by the following equation (2).

$$P_l = -\sum_{j=1}^{n-m} H_{l,j} S_j - \sum_{j=1}^{l-1} H_{l,j+n-m} P_j \quad (2)$$

[0061] By satisfying equation (2), k parity bit's values of the whole parity bit's values are obtained.

[0062] The lower part parity calculator 260 obtains parity bit values of the un-diagonalized part using Gaussian elimination or equation (1). Since the parity bits, excluding k parity bits obtained by the backward-substitution calculator 250 from p parity bits, are excluded in constructing the triangular matrix T by the triangular matrix extension unit 240, a matrix such as matrix C shown in FIG. 4a is a reduced form of the original matrix H.

[0063] FIG. 5 is a flowchart of a method of generating parity data based on the low-density parity check matrix, which will be described in conjunction with FIG. 2.

[0064] The parity check matrix generator 210 generates a c x p parity check matrix H, where a value c is a number of columns and length of a codeword and a value p is a number of rows and length of parity data, in operation 501.

[0065] The column permutator 220 reorders the columns of the matrix H from left to right in the order of highest entry of an element having a value of one in each column, resulting in a reordered parity check matrix H' , in operation 502.

[0066] The triangular matrix generator 230 determines a cross-point I of the diagonal line $L1$ of the reordered parity check matrix H' and the diagonal line $L2$ of the parity matrix part, in operation 503.

[0067] In operation 504, a triangular matrix T is generated by exchanging columns of the reordered parity check matrix H' , in accordance with the positions of elements having a value of one of all the rows above a horizontal line $L3$ that pass the cross-point I .

[0068] A first column exchange is performed between a left-most column of a message matrix part Mm and a left-most column of a parity matrix part Mp .

[0069] That is, referring to FIG. 3C, a column $C1$ of the message matrix part Mm and a column Cx of the parity matrix part Mp are exchanged.

[0070] Then, a second most left column $C2$ of the message matrix part Mm and a second most left column $Cx-1$ are exchanged. Similar column exchanges are sequentially performed on the remaining columns.

[0071] In operation 505, it is determined whether a row, under the horizontal line $L3$, in which a second element from right to left having a value of one is to the left of the diagonal line $L2$.

[0072] If such a row exists in, the triangular matrix extender 240 performs a plurality of row and column exchanges (permutations), thereby diagonalizing an un-diagonalized matrix C to the maximum extent in operations 506 and 507.

[0073] In other words, in operation 506, of all the rows under the horizontal line $L3$, a row in which a second most right element having a value of one of all elements having a value of one in the row is to the left of the diagonal line $L2$, is extracted, and then, the extracted row, e.g., $R3$ of FIG. 4B is exchanged with a top-most row, e.g., $R1$ under the line $L3$.

[0074] Thereafter, in operation 507, a column Cq on the right of the diagonal line $L2$, which has an element having a value of one corresponding to the extracted row, e.g., $R3$, is

exchanged with a column C_p on the left of the diagonal line L_2 , which has an element having a value of zero corresponding to the extracted row, e.g., R_3 .

[0075] In a similar way, row and column permutations are repeatedly performed in operation 508.

[0076] As such, a parity check matrix including a triangular matrix is regenerated in operation 509.

[0077] In operation 510, the backward-substitution calculator 250 performs a backward-substitution calculation using message bits and the area of the triangular matrix extended by the triangular matrix extension unit 240, thereby obtaining parity data, and the lower part parity calculator 260 obtains parity bit's values (parity data) of an un-diagonalized part according to Gaussian elimination or equation (1).

[0078] In such a method according to an aspect of the present invention, the computations required to generate parity data are reduced, thereby efficiently obtaining the parity data.

[0079] According to other aspects of the invention, the calculator, or other unit of the apparatus, is a computer implementing the method shown in FIG. 5 using data encoded on a computer-readable medium.

[0080] Although a few embodiments of the present invention have been shown and described, it would be appreciated by those skilled in the art that changes may be made in this embodiment without departing from the principles and spirit of the invention, the scope the scope of which is defined in the claims and their equivalents.